GROUND IMPROVEMENTS FOR EMBANKMENT SECTIONS ON THE SOFT GROUNDS IN INCHEON BRIDGE PROJECT

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Abstract : *In case of the western connecting road section of the Incheon Bridge project, the route was classified into 5 zones depending on soft ground characteristics and the ground improvement methods. Sand compaction piles, prefabricated vertical drains, and pre-loading technics were applied in parallel depending on each zone. In case of each method, diversified data and a lot of information for the constructional instructions are available as a general application for the soft ground but we intend to summarize it according to the construction flow based on the case of our site.And rational design constants were computed based on the soil survey performed in the toll plaza section of the project.The soft ground improvement method was selected to promote the constructability and economic efficiency according to the characteristics of the soft soil, site conditions and features of the structure. The stability of the toll plaza section was secured by examining the appropriateness of the selected soil improvement method.*

Keywords: soft ground, ground improvement, Incheon Bridge, PVD, SCP

1. INTRODUCTION

There are soft clayey deposits in the subsurface of the Incheon Bridge. Therefore, it was needed to improve the ground properties to construct the road on these deposits. Westrn connecting road section

funded by the governemnt and toll plaza section funded by the private concessionaire are located in Yeongjong Island area. And they are the route consist of embankments on the soft ground. Abutment area at the end of the bridge (in the area of Songdo New Town) also has the soft layers. Figure 1 shows these sections.

Figure 1 : Embankment Sections on the Soft Ground in the project

Soft ground is a relative concept that it is unable to withstand upper structures due to weak shear strength or a big deformation is taken place there under the current situation that the structures are getting large scaled, more extensive concern and research for the handling method of soft ground are under progress.
Prefabricated vertica drain (PVD, or PBD for 'plastic board drain'), sand compaction pile (SCP), horizontal drainage methods were applied to improve the subsurface characteristics. Geosynthetics made of natural fiber, or geotextiles were used as drainage material as well as sand, or crushed stone scraps. Light embankment method using the EPS (expanded poly styrene) blocks were also applied at the backfill zone of the bridge abutment. And field instrumenatations and various types of the geotechncial explorations were performed to monitor the ground behavior.
Detailed descriptions about the ground improvement technics for the embankment road and toll palza area are reviewed.

2. GROUND PROPERTIES AND DESIGNS

Insitu tests and laboratory tests were carrid out to investigate the subsurface properties. Soft layers containing silt and clay were classified as CL, or ML soil and N-value from the SPT is less than 6 for the depth between 2 m and 20 m below the surface. Some parameters of the ground are shown in Table 1.

Table 1: Design parameters of soft deposits

Parameters			values
Physical properties	Specific weight (kN/m^3)		approximately 18
	Initial void ratio		approximately 1.1
	Liquid limit, LL (%)		25 - 60
	Plastic index, PI (%)		5 - 38
Consolidation characteristics	Compression index		approximately 0.25
	Vertical coefficient of consolidation (cm^2/sec)		(2-3)×10^{-3}
	Horizontal coefficient of consolidation (cm^2/sec)		approximately 1.3
	Permeability coefficient (cm/sec)		(1-2)×10^{-7}
Shear strength characteristics	Consolidated undrained shear strength, Cu (kPa)	0m~5m	7 - 15
		5m~10m	20 - 30
		< 10m	25 - 50
	Strength increase rate, m		approximately 0.18
Banking/filling material	Specific weight (kN/m^3)		approximately 19
	Cohesion, C (kPa)		approximately 15
	Angle of internal friction, ø (deg)		25 - 30

2.1 West Connecting Road Section

This section is one of governemnt-finaced sections of the Incheon Bridge project. Because this section consists of embankment highway and several single span bridges, length of this roue is excluded from the total length of the Incheon Bridge.

Table 2 : Project Outline of the West Connecting Road in Yeongjong Island

Location	Starting point	Unseo-dong, Joong-gu, Incheon Metropotitan City (Incheon International Airport Expressway)
	Ending point	Unnam-dong, Joong-gu, Incheon Metropolitan City (Toll plaza of the Incheon Bridge)
Description	Scale	Total Length : 2.4 km Road Width : 30.6m (6 Lanes for 2-way traffics) 1 Interchage and 1 Junction are included
	Bridges	10 single-span bridges / Total Length of Bridges : 772m
	Soft Ground Area	Station (STA) 1k+000~2k+400 and Yeongjong IC Area

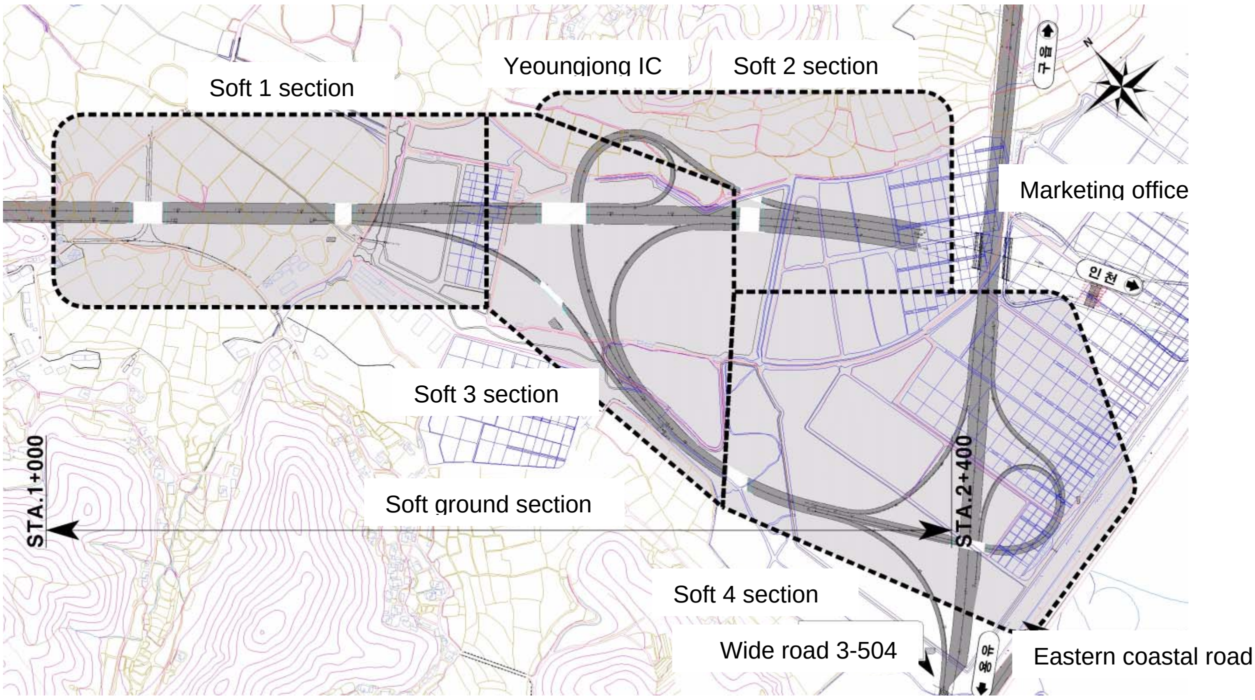

Figure 2 : Soft Ground Zonning in the West Connecting Road of the Bridge

STA.1k+000-2k+400 of this section consists of paddy fields and salt farm formed by soft ground of clay and silt and pre-loading method, PVD and SCP method as a vertical drain method and fiber-mat and gravel mat as a horizontal drain method have been applied as a method of handling soft ground based on the design (Table 3). Pre-loading, PVD and SCP method applied for our site have many cases of application as a general method of handling soft ground but we wish to contribute to the constructability enhancement and long term securing of stability for the upper structures of soft ground through the reduced trial and error of the site engineers by summarizing the construction flow and constructional instructions based on the site case.
Soft ground of this site is classified into total 5 sections (wide road section) based on the applied method, installation distance and detail treatment period and SCP method for section 2-4 and combined method of

SCP and PVD for section 4-1 section have been applied and the other remaining sections were designed by PVD method. In case of soft ground section 2-4, SCP method has been applied for shortening the work period (embanking speed: 2 m/month) and SCP method has been applied for the soft ground section 4-1 in order to prevent activation. In addition, in case of PVD section, it was designed with fiber-mat as a horizontal drain mat and in case of SCP section, it was designed with gravel as a horizontal drain material and the main method and design status per each section are as followings.
Space between each PVD varies from 1.2 to 2.3 m and space between each sand compactio pile is 1.8, or 2.0 m. Geotextile mat to help the horizontal drains and reinforcements has a tensile strength of 30, or 50 tonf/m.

Table 3 : Applied methods for Ground Improvement

Classification		Applied method	Remarks
Consolidation facilitating method	Vertical drain	PBD + SCP	PBD : plastic board drain (= PVD) SCP : sand compaction pile EPS : expanded poly styrene [Geotextile] PET : polyester PP : poly propylene
	Horizontal drain	Natural Fiber Drain Mat, or Smashed Stone Mat	
Activation prevention method		PET Mat + SCP	
Surface layer treatment		PP Mat	
Pier lateral flow prevention method		EPS Method	

2.2 Toll Plaza Section

The toll plaza is located in the west side of Incheon Bridge in a section of about 500m between STA. 2k+400 and 2k+900. The plaza occupies an area of 88,400m^2 including the main road, U-turn section, lot for the main building for the maintenance office, and parking. An embankment structure is planned with regard to the soft soil characterizing the toll plaza section.

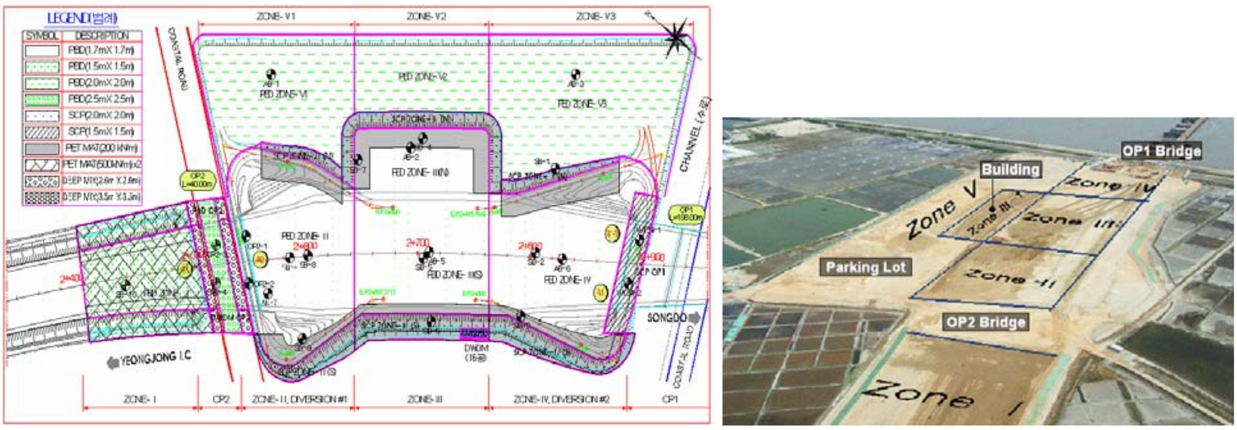

Figure 3 : Plane view of the toll plaza section of Incheon Bridge

In the project section, the clay is slightly overconsolidated (OCR = 1.3~4.3) and is assumed as normally consolidated for conservative design. Planar drainage conditions are considerd since weathered soil and weathered rock with SPT N ≥ 30 are distributed at the bottom of the soft layer. The compression index method (Cc) is used to compute the consolidation settlement.
The soft ground improvement period runs over 20 months including the stage-by-stage banking works and settlement period. Considering that the embankment height reaches approximately 10 m, two or less

stage embankment is planned. The criterion for residual settlement is set to 10 cm. Embankment height for this area is up to 11 m and thickness of soft layer is 11-20 m.
Results of stability check without consolidation is shown in Table 4. Ground improvement technics applied are summarized inTable 5.

Table 4: Results of stability check without consolidation

Works	Survey results without consolidation	Problems	Solutions
Consolidation	More than 968 months required	Total improvement period exceeding 20 months	Accelerated consolidation method required
Stage embankment	More than 4 stages required	Need for less than 2-stage embankment considering construction period	Soil motion (activity) prevention method required

Table 5: Treatment methods for soft ground

	Applied methods
Vertical drainage	Preloading method + PVD
Horizontal drainage	Sand mat (thickness > 50cm)
Shear failure preventions	SCP + High strength PET mat

The formula proposed by Hansbo is applied as a formula considering the smear effect and well resistance produced by the soil disturbance since it has been reported that its results are in agreement with the measured values.
Considering that the soft ground improvement period including the embankment works is running over 20 months and based on the results of the check of the prefabricated board drain (PVD) spacing, it appears that dimensions of 1.9m×1.9m for zone-A, dimensions of 1.7m×1.7m for zones B, C, D and OP1 bridge and OP2 bridge, and dimensions of 2.0m×2.0m for zone-E are adequate. The dimensions are modified to 1.7m×1.7m for zone-A since zone-A is the section in contact with the abutment at the start of bridge-OP2.
In order to secure the stability of the embankment slope during operation, sand compaction piles (SCP) of 2.0m×2.0m and PET mat (200 kN/m, L=25m) are applied in parallel in the main road section. Sand compaction piles (SCP) of 1.5m×1.5m are applied in the temporary slope at the abutments of OP sections to prepare for future lateral motion.
Results of stability check with ground improvement at design stage is shown in Table 6. To secure the stability of the slope of the embankment of the main road, the loading embankments of the main road and U-turn section shall be constructed simultaneously.

Table 6: Results of Check of Soft Ground Treatment Methods

Stage		Embankment height (m)		Safety factor	Loading duration (month)			Settlement	Residual settlement	PBD spacing	Ground treatment
					Banking	Resting	Total				
Embankment stage	Stage 1	6.5	6.5	1.32	4.3	4.6	8.9	100 cm	Less than 5 cm	1.7×1.7 (m)	SCP + PET mat
	Stage 2	5.3	11.8	1.42	3.6	5.9	9.5	53 cm			
	Operation	–	–	1.40	–	–	–	–			
	Total	–	11.8	–	7.9	10.5	18.4	153 cm			

3. GROUND IMPROVEMENT METHODS

3.1 Prefabricated Vertical Dain (PVD) Method

Vertical drain method has been made to increase early consolidation settlement and ground shear strength by shortening underground drain distance and enhancing permeability in a way of installing artificial drain materials and it is classified into sand drain, paper drain, and PVD depending on its employed materials and construction method. The term of PVD is usually called as PBD (plastic board drain). This method was applied to expressway construction site in early 1990 for the first time domestically and this method has been widely used as it has limited occurrence case of smear effect and well resistance when using drain materials compared with sand drain mat and its construction speed is comparatively faster and diversified core shape and filter like fiber drain has been developed
Soft ground construction with application of PVD differs depending on applicability of other items including horizontal drain materials and water well but in case of this site, PP-Mat, Fiber-Mat, horizontal drain materials, PET-Mat for activation prevention over the original ground have been applied in an orderly manner. In case of treating soft ground, it should be noted that quality assurance of the structures could be attained through the ground improvement by consolidated settlement when the construction flow is uniformly carried out without any given weight at each stages.
It should be confirmed to see if PVD method applied section of the design document and construction distance are matching with quantity estimation and by preparing construction layout drawing for each section, it should be controlled per each section by comparing PVD construction depth based on soft ground depth of quantity estimation with that of this construction.

Figure 4 : PVD Materials

Operability of casting equipment shall be confirmed by performing test construction before the main construction and ground survey, design depth and actual construction depth shall be confirmed. In addition, initial setting condition shall be determined by comparing the depth of punching automatic record attached to PVD construction equipment and actual construction depth. At the time of main construction, daily working section, punching depth, accumulated punching quantity shall be recorded and submitted to the inspector together with the record sheet.
Punching equipment can be classified into two: one is to use vibrating camber and the other is to punch by static load by using hydraulic force. Currently punching equipment by static load is being widely used including the case of this site but in order to prevent ground instability to be caused by an excessive pore water pressure during punching, punching equipment shall be checked without fail. In order to minimize ground interference during PVD punching mandrel size or anchor plate size shall be considered based on construction depth. Because in case of anchor bolt, if its size is too small, stacking up phenomenon may be taken place and if too big, consolidation delay by ground interference may be occurred.
PVD could be punched after pre-boring with the breaker in teh ground which has stiff surface layer.

Figure 5 : Automatic casting recorder and Tip of the mandrel

Future schedule shall be established after estimating mobilization timing and number of equipments to be mobilized considering daily work volume (app.7,000m) and fabrication period (app. 3 days) from the total quantity confirmed by quantity estimation in order to prepare a construction schedule. Mobilization timing of PBD equipment shall be decided reflecting preparation progress for PBD construction including PP Mat installation and field delivery period.
In case of this site, it took 15 days for equipment delivery on site and fabrication and constructability has been sometimes disturbed by PBD equipment inoperable condition during working caused by failing to secure working space considering daily average work volume at the time of initial delivery. Therefore, it is considered to be required to decide equipment mobilization timing considering progress status of other works rather than advanced equipment mobilization.
A lot of PBD material delivery may be exposed to quality deterioration by field storage but short delivery may affect constructability due to unbalanced material supply.

3.2 Sand Compaction Pile (SCP) Method

SCP, a kind of vertical drain method, was developed by Japanese Boodong Construction Co.. 50 years ago as a method of increasing shear strength by creating large bore compaction sand piles forcefully in order to increase supporting force, prevent activation and restrict lateral deformation of the soft clay ground. In addition this method has an effect of reducing consolidat4ed settlement volume by stress distribution effect of sand pile and preventing liquefaction by density increase. When performed together with loaded embankment, initial embankment level is increased and the work period could be shortened and simultaneous improvement both for sandy soil and clay soil could be obtained very effectively and its characteristics is as follows. Increase of cutting resistance, supporting force and preventing sliding failure as compaction sand pile and clay ground are forming composite ground. Sand drain effect is expected. (early finish of settlement) Reducing uneven settlement by the function of composite ground
This method has been started to be used as a counter-measure method against ground liquefaction at the time of Niigata earthquake in 1964 and currently this method is being widely used for soft ground improvement works of the reclaimed areas. At present, a substitute material is under study due to sand supply problem and cost increase and one of the typical methods is gravel compaction pile (GCP) method. In case of this site, GCP method was considered at design stage but clogging problem has been emerged as an issue.
According to a research thesis, when comparing SCP and GCP method by using cylindrical model with diameter of 20cm and height of 40cm, it was revealed that supporting force of SCP when substitution rate is 50% is bigger than that of SCP by 1.54 times.
Vibration type composure method of forming sand compaction pile by drawing casing after punching casing with vibrator, pouring sand and then compacting with vibration was applied.

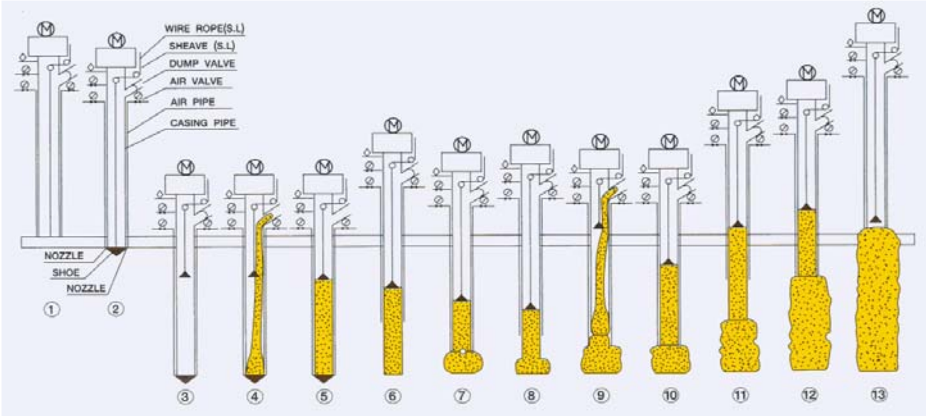

Figure 6 : SCP Construction Sequence

At the west connecting road section, it was confirmed that vibration effect of SCP construction was extremely minimal and noise was below 60dB that would not create any pubic complaints. In this section, As a result of field tests, sand pile formation by confirming through excavation of upper part, possession over diameter 600 mm was confirmed notwithstanding sectional reduction for upper part landfill and gravel mat and at the lower soft ground inside, it is judged that construction could be performed over design diameter. In addition, equipment value for current value is normally controlled by management criteria based on SCP driving control criteria and it could be judged that at the time of using 300-320A, 440V generator, when current value records 200-240A, punching was implemented up to soft ground depth. In this section, 440V generator was being used and as a result of test construction, as punching degree was minimal at the current value over 220A, the current value over 220A was selected as control criteria for this project.

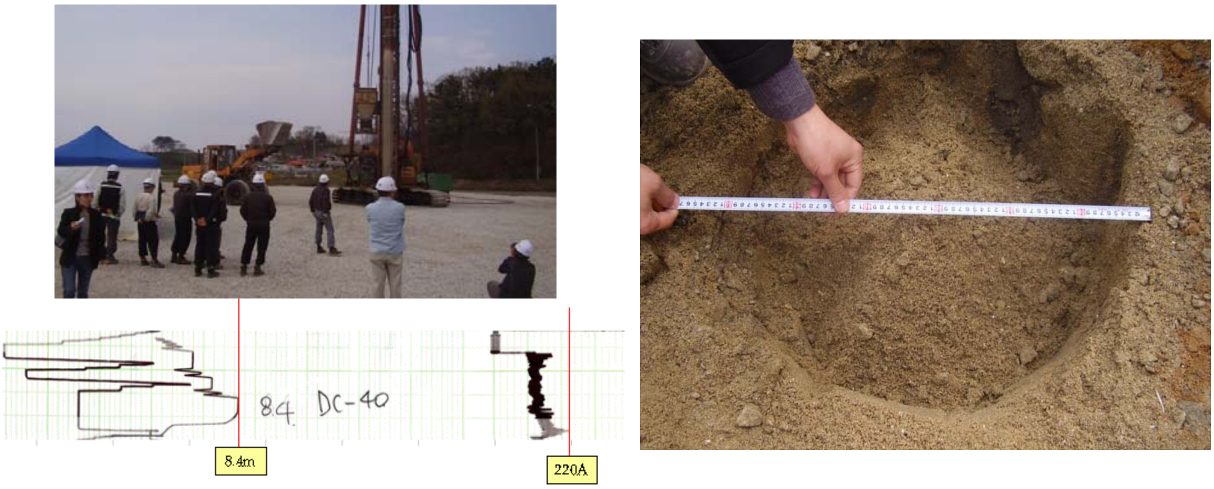

Figure 7 : Record sheet and construction photo

3.3 Geosynthetics and Horizontal Drainage

In order to ensure separation from the original ground and permeation, geotextile mat made of PP and PET was installed and it was delivered on site after pre-fabrication at the shop and it was required to confirm by comparing it with traverse width of quantity estimation. PET mat has versatile functions of drainage, separating, reinforcement, and others. To spread PP-mat and PET-mat, ground surface should be arranged to be even so that these materials will not be wrinkled or overlapped during installation and within 10 days after mat installation, in order to prevent any damages by UV rays and equipment

movement, landfill should be made on top of this materials in principle and mat sealing should be made by using the same materials over 2 lines if possible with ensuring overlapped length over 40cm. In case of field sealing, when mat sealing should not be complete at the time of landfill, sealing joint may be damaged and its function may be affected adversely.

In addition, through field survey considering thickness by original ground landfill before measurement after PP-Mat installation, cross section of embankment slope shall be marked and then affordable width of mat to be rolled along with the slope in the future shall be confirmed. (It is required to secure affordable width over 2.0m from the end)

Figure 8 : PP-Mat Spreading

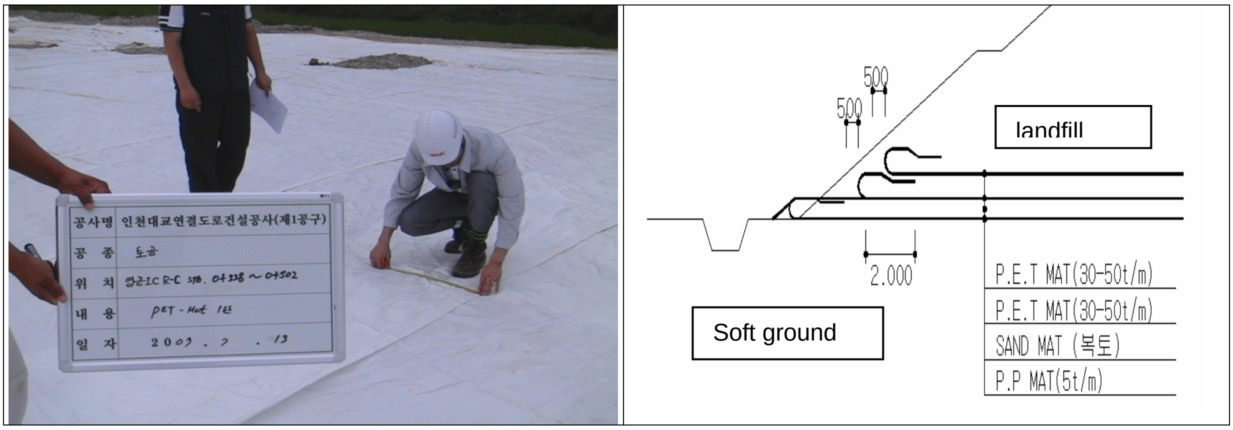

Figure 9 : PET-Mat casting and layout

Conventional sand mat method was used for the horizontal draingae at the ground surface. Smashed stone mat was also applied. And special strip-geosynthetic drainage system made of natural fiber (fiber-mat) was used in the west connecting road section. Fiber-Mat is a drain materials made of palm fiber by making it like a plate shape after textured compression and its outside is covered with double layer jute filter in order to protect against soil particle influx and it has been developed as a substitute for sand Mat. In addition, it has an environmentally friendly property of being decomposed underground after finishing drain function as it consists of a natural fiber. As it was developed as a substitute for an expensive and hard to get sand mat, its disadvantage is as follows.

Figure 10 : fiber Mat construction map and PBD fastening method

In case that fiber mat is exposed to rain water or moisture at the site storage, mat strength would be lowered by frost boil and Fiber part that displays tensile strength would be damaged in the future. Therefore, when material ordering, material shall be ordered considering daily average construction volume and schedule from order to on-site delivery and delivered fiber-mat shall be kept at well ventilated place that is distanced from the ground surface by a certain length.

Figure 11 : Fiber Mat damage example

4. QUALITY CONTROLS FOR THE STABILITY OF THE EMBANKED GROUND

Field instumentaions and checking investigations were performed to secure the stability of the ground and the embankment. Final amount of the consolidation settlement was also estimated according to the construction schedule.
Electronic piezo-cone penetration test (CPTU, CPT) during the embankment construction was the best tool to check the strength increasement by the ground improvements and useful infomation to check the stability of the ground were obtained from this test. The authority (Korea Expressway Corporation) supported the track-mounted truck system CPT equipment. At the time of design, stage by stage embankment for each section is planned with 3 stages in most cases and the embankment level is diversified with 4.9-14.7m. Confirmation for the additional embankment after stage by stage embankment is performed by CPT at the completion time of negligence period of each stage and at this time stability analysis for the embankment material according to strength increase of the ground and additional embankment will be carried out. In case of this site, stage by stage embankment confirmation is referred to Expressway & Transportation Research Institute. CPT is scheduled depending on original ground and each stage and by recording coordinates through a survey at the time of original ground test, exact ground strength data could be obtained by performing a test at the existing test location at the time of future embankment. Provided that in case of SCP section, it is required to secure coordinates of 6-10 places between disposition distances. In case of determining CPT test timing based on measured data, it is desirable to perform the test after passing scheduled negligence period but if the test should be

scheduled at the time of negligence period of app. 80% depending on measured result and site condition, some soft ground schedule could be shortened. Figure 13 shows the result of the stability analysis using the CPT data sccording to the embankment stages.

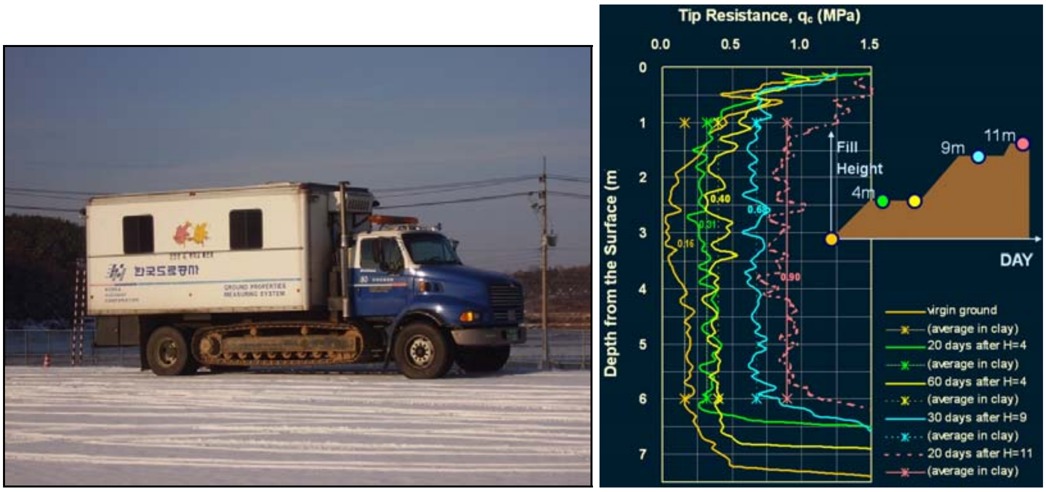

Figure 12 : CPT using track mounted truck during the embankemnt constructions

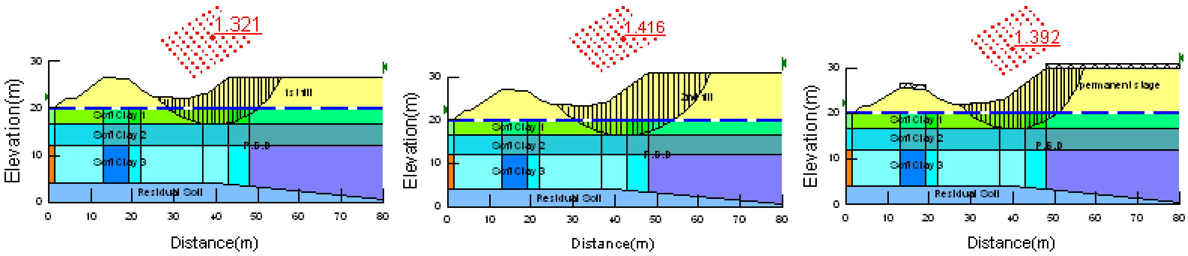

Figure 13 : Stability Check using the CPT result according to embankment stages

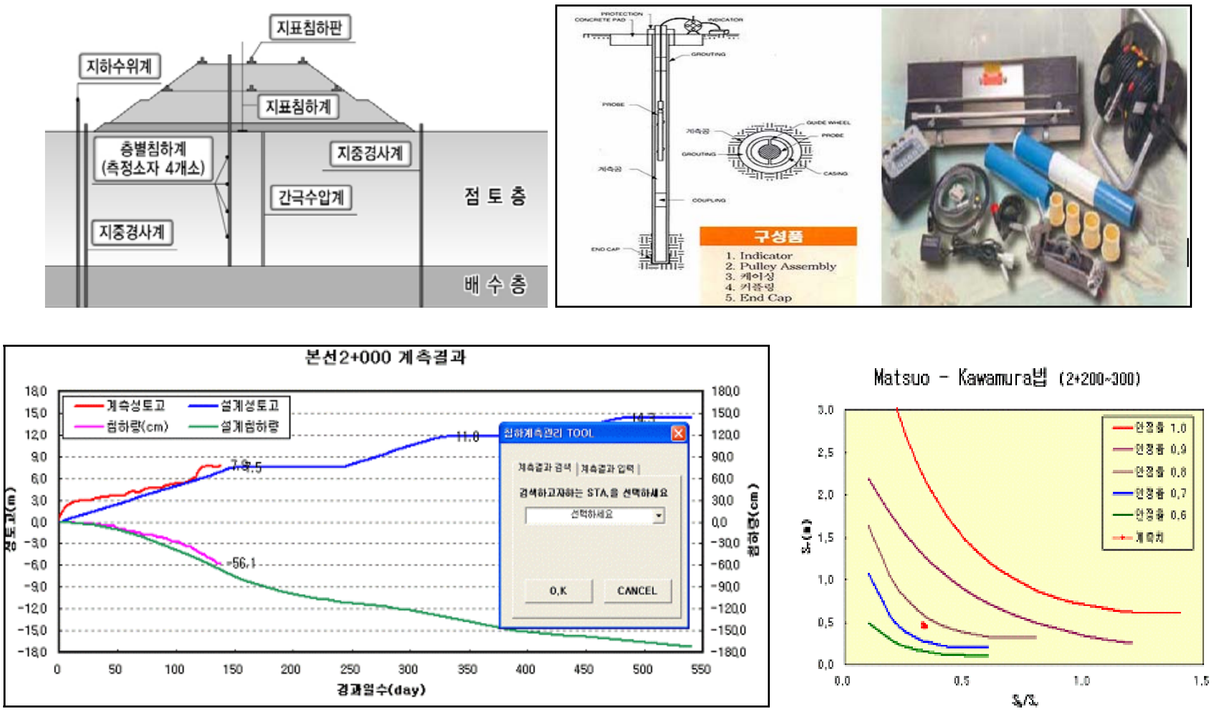

Figure 14 : Field Instrumentations and monitoring the ground behavior

5. CONCLUSION

Currently, a research on ground improvement through soft ground treatment has been progressed considerably as a general tendency in order to achieve enlargement of super structures and utilization of reclaimed areas and in case of Incheon Bridge connection road 1st section as well, PVD, SCP method and pre-loading method have been employed in parallel for the treatment of soft ground.
PVD, or SCP method has been applied in may cases as a soft ground treatment method in general and though a lot of relevant research data or field case-related data are available, procedure and instructions as per each stages of construction based on the case of this site have been explained herein. Numerous matters to be reviewed and check points according to the site situation or ground condition were evident during the construction and also some matters were desired to be fulfilled. Mat casting through original ground arrangement and equipment operability possession by securing sections related with the ground surface objects and public complaint in advance and embankment speed control and drainage route possession including soil gutter at the time of upper embankment through measured data could be mentioned as the most fundamental matters primarily and then quality control for PBD and SCP construction and CPT for stage by stage embankment timing confirmation could be elaborated as the next important factors secondarily.
In case of soft ground site, as the subsequent structural process like bridge construction is depending on the soft ground treatment process, it should be emphasized that securing process affordability through successful control of soft ground will ensure acceptable quality and work period for the overall structures. It is admitted that the construction case of this site did not elaborate any new findings through a test or research but in case of applying the same soft ground treatment method in the future, we hope that this case may be able to be contributive for reducing any constructional trial and error to the minimum at least.

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